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AN ATTEMPT AT SPECTRAL DETECTION OF PHENOLOGICAL CHANGES OF BOREAL VEGETATION

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Abstract: Ground truth information for remote sensing to distinguish boreal and arctic vegetation species, biomass and phenology is needed in global scale climate change research activities. A boom-mounted 4-band spectroradiometer was installed to measure seasonal radiance patterns in green (560 nm), red (660 nm), near-infrared (830 nm) and mid-infrared (1650 nm) spectral bands from boreal vegetation canopies over the 1992 growing season in northernmost Finland, Utsjoki. The radiometer on top the rotating boom which was held horizontally about 4 m high above the ground looked downward on four plant plots in turn every 15 min. Plant growth stages were observed every week for each plot. Seven-band field spectra (560, 660, 830, 1100, 1200, 1650, 2200 nm spectral bands) were also taken there for autumn tint and leaf coloring of the major plant species at the end of August, 1992. Initial analyses indicated that the "wetness" index (near- to mid-infrared reflectance ratio) and red band reflectance could be potential indices to evaluate the autumn leaf coloring and withering of dwarf and mountain birch tree canopies.

1. Introduction

Climate change such as global warming will drastically affect vegetation activity. To clarify this hypothesis, year-to-year change and long term shift in the vegetation phenology must be precisely detected over the vast boreal and arctic area. Satellite remote sensing is a promising technique to resolve this problem. However, we need to examine the usability of spectral reflectance data for detection of seasonal and phenological changes in boreal vegetation.

PETERSON (1992) made ground-based visible to near-infrared reflectance measurements and found that boreal forest clear-cut communities could be discernible on the basis of the seasonal reflectance profile peak value and the time of the peak value occurrence. COHEN and SPIES (1992) argued that the "wetness" index, which is the contrast of TM Bands 5 and 7 (mid-infrared) with Bands 1-4 (visible and near-infrared) derived from LANDSAT data, can describe the canopy maturity of the Douglas-fir/western hemlock forest.

These papers encouraged us to verify seasonal profiles of visible to mid-infrared reflectances. Hence, seasonal ground-based measurements at short time intervals (less than one day) in the visible, near- and mid-infrared ranges were conducted in northern Finland at 69°N to detect the phenological change of reflectance in accordance with the development of plant growth and senescence.

The main objectives of this paper are: (1) to ascertain the utility of a visible to mid-infrared boom-mounted 4-band spectroradiometer for detection of seasonal and phenological changes of subarctic vegetation in Finland, and (2) to obtain canopy bidirectional reflectance factors from common species of subarctic and peat bog vegetation in Finland to assist in interpretation of the results of the boom-mounted radiometer data.

2. Materials and Methods

2.1. Automated measurement of seasonal spectral change of boreal vegetation in Finland

2.1.1. Measuring equipment

The boom-mounted 4-band radiometer designed at the National Institute of Agro-Environmental Sciences has three silicon-photodiodes for the 560, 660 and 830 nm bands, and a germanium-photodiode for the 1650 nm band as the light detectors. The light sensors and bandpass filters are assembled in a waterproof cylindrical case 15 cm in diameter. This sensor module was calibrated by a standard light source (500 watts) ranging in temperature from 4 to 30°C.

The sensor module looks vertically downward from 4 m above the ground, allowing radiance measurements of a 0.6 m diameter area to be made. The sensor module and a counter balance were mounted on the tips of both sides of a 4 m long boom made of steel pipes. An electric motor turned the boom. The position at which the sensor module is looking can be estimated from the boom direction angle, which is sensed by the voltage drop of a potentiometer coupled to the motor axis. The motor and boom with the sensor module were installed on top of an aluminum tower 4 m high. A photograph of our measuring system is shown in Fig. 1.

The sensor module was automatically rotated and positioned above the center of four vegetation plots around the tower one after another every 15 min from 6 a.m. to 6 p.m. every day. The data logger stored the date and time, 4-band radiances, sensor temperature, boom direction angle (sensor position), a solarimeter and four albedo sensors' output voltages. The logged data were downloaded into a handheld computer every two weeks.

The whole system was sent to Kevo Subarctic Research Institute (KSRI, Kevo, University of Turku) in Utsjoki on May 27. After the system was assembled, data acquisition started on May 29 and finished on September 28, 1992.

2.1.2. Research site

The geographic area of this research is shown in Fig. 2. Kevo is located in Utsjoki (69°45′N, 27°E, 80 m a.s.l.). "Most of the country is mountain birch (*Betula pubescens* ssp. *tortuosa*) forest, while areas lying above 300–350 m are

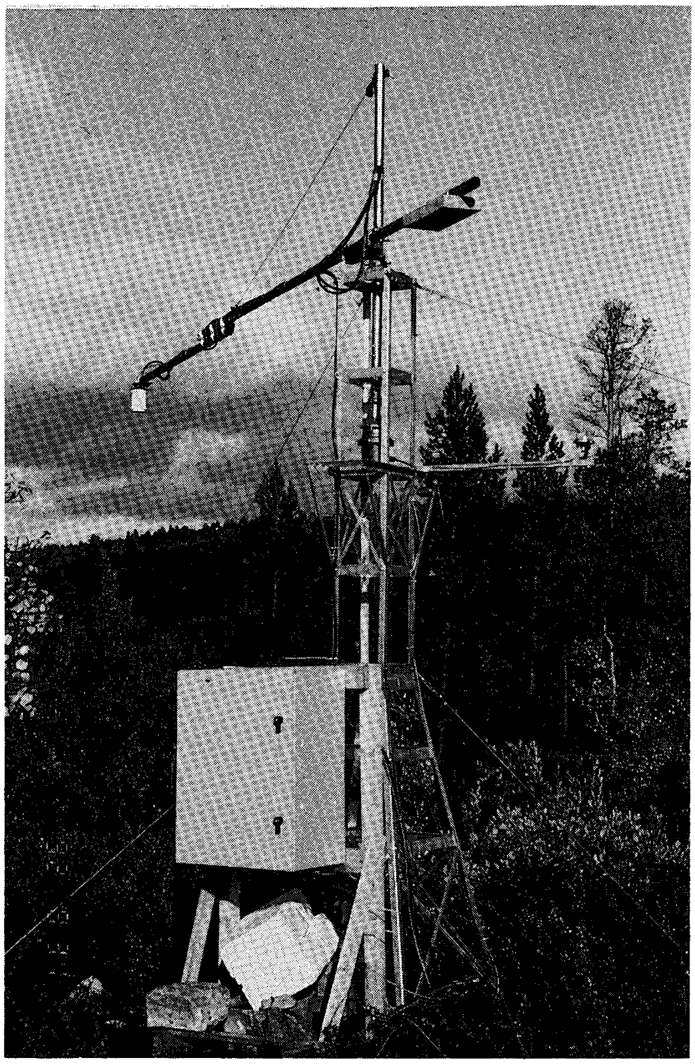


Fig. 1. The measuring system at Kevo Subarctic Research Institute.

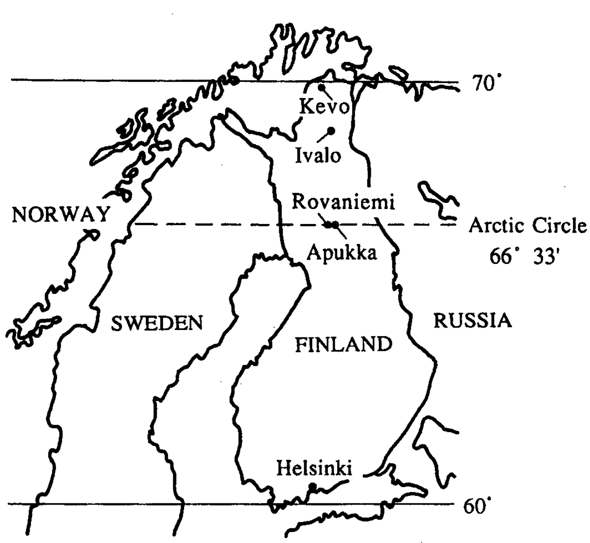
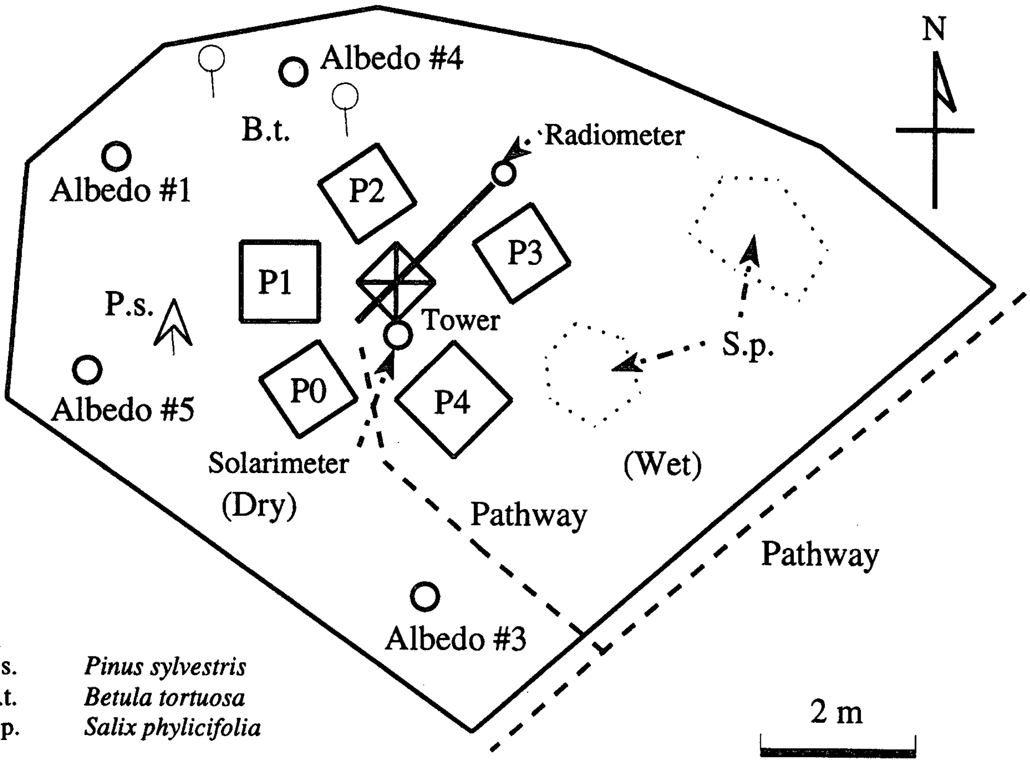


Fig. 2. Site locations in Finland. Kevo and Apukka.

low treeless alpine heaths. Dwarf shrubs and vegetation rich in lichens and mosses are typical. Around the research station, however, there is an isolated pine forest which follows the Utsjoki and Kevojoki river valleys" (KSRI, 1987). There are pine trees (*Pinus sylvestris*) at the edge close to the rivers because of its milder climate. The dominant tree species is mountain birch (*Betula tortuosa*). At higher altitude, dwarf birch (*Betula nana*) prevails over mountain birch. Representative undergrowth is black crowberry (*Empetrum hermaphroditum*).

The schema of the experimental site in Kevo is illustrated in Fig. 3. The sensor module of the 4-band radiometer was turned and stopped above the centers of four 1 m × 1 m target plots located around the tower. Four albedo sensors were set around the site. A solarimeter was installed half-way the tower.

Plant cover, height, leaf color, phenological stage and flowering information with photographs of plants including mosses and lichens growing in each plot were observed once a week starting June 12.



P.s.	*Pinus sylvestris*
B.t.	*Betula tortuosa*
S.p.	*Salix phylicifolia*
Plot	
P0	*Betula nana, Empetrum hermaphroditum, Ledum palustre*
P1	*Betula nana, Empetrum hermaphroditum, Vaccinium myrtillus*
P2	*Betula tortuosa, Empetrum hermaphroditum, Ledum palustre*
P3	*Betula nana, Empetrum hermaphroditum, Ledum palustre, Vaccinium ulginosum*
P4	*Betula nana, Empetrum hermaphroditum, Ledum palustre*
Albedo	
#3	*Betula nana, Vaccinium ulginosum, Ledum palustre*
#5	*Betula nana*
#1	*Ledum palustre, Vaccinium ulginosum,* lichens
#4	*Vaccinium ulginosum, Ledum palustre, Empetrum hermaphroditum*

Fig. 3. Schema of the test site and dominant species at Kevo.

2.2. Collection of hand-held radiometer data in Finland

A seven-band portable field spectroradiometer consists of a hand-held sensor-filter module with 10-degree field of view optics, an electronics unit with batteries and a portable computer. The center wavelengths of 7 bands that partly replicate the LANDSAT TM reflectance bands are 560, 660, 830, 1100, 1200, 1650 and 2200 nm. Reflectance factors are relative to reflectance of a $BaSO_4$ standard panel.

Data were collected *in situ* 0.5–2 m from the target at Utsjoki on August 29, 30 and 31, and also at Apukka on the Arctic Circle (66°33′N) and about 20 km north-east of Rovaniemi on September 4 (Fig. 2). Unfortunately, most of the measurements at Utsjoki were made under overcast conditions. It was sunny and cloudless on the day of measurement at Apukka.

3. Results

3.1. Seasonal spectral characteristics of the vegetation in Kevo

3.1.1. Phenological changes of representative plants at the site

The plant heights and percentage cover of the major species were stable from June through August. The starting date of spectral measurement was not early enough to observe budding and early vegetative stages. The leaf color of mountain birch (*B. tortuosa*) in Plot #2 was turning yellowish green on August 20 (233rd day of year, DOY233), and turned yellow from August 27 to September 10 (DOY240–254). The leaves had turned brown and died by September 17 (DOY261).

Dwarf birches (*B. nana*) growing in the other plots were flowering on June 12 (DOY164) but no flowers were observed a week later. About August 27 (DOY240) their leaves began to turn yellow, and then had orange color leaves on September 3 (DOY247). Leaf color was brown on September 10 (DOY254), and all of the leaves were dead on September 17 (DOY261). Black crowberry (*Empetrum hermaphroditum*) showed no significant change during the measurement period.

The amount of precipitation in June and July, 1992, was two to three times as much as in an average year.

3.1.2. Progress of the experiment and machine troubles

After a week from the installation, gears in the boom control motor were damaged. The sensor module was looking at only Plot #0 for about two months until the end of July. In August and September, measurements were made for Plot #1 through #4 without problem. Besides the breakdown of the motor, malfunctioning was found in the 660 nm band output. Hence, the radiance data of 560, 830, and 1650 nm bands excluding the 660 nm band were analyzed.

3.1.3. Seasonal patterns of biband vegetation indices

Spectral two-band radiance ratios, differences, and differences divided by sums which were analogous to that of NDVI (Tucker, 1979) were calculated using all of the two-band combinations from three bands, and plotted against incident solar energy. Radiance of the x nm band will be indicated by Lx in the text. In Fig. 4, *L560/L830* and *L830/L1650* versus solar energy are presented as typical examples, respectively. These band ratios might be useless at a solar radiation level less than about 200 W/m^2. This lower limit of solar radiation is common among the other results of two-band calculations (data not shown).

L560/L830 and L830/L1650, taken when the solar energy was larger than 200 W/m^2, were plotted on the time dependence charts (Fig. 5). The plotted points were smoothed by using 7-day running means. The numerals indicate the vegetation plot numbers.

The profiles of *L560/L830* give two peaks at around DOY210 and 240 which seemed to be caused mainly from the temporal oscillations of two band outputs. However, the cause of fluctuation in the ratio has not been resolved so far. MILLER *et al.* (1991) investigated seasonal patterns in tree leaf reflectance and

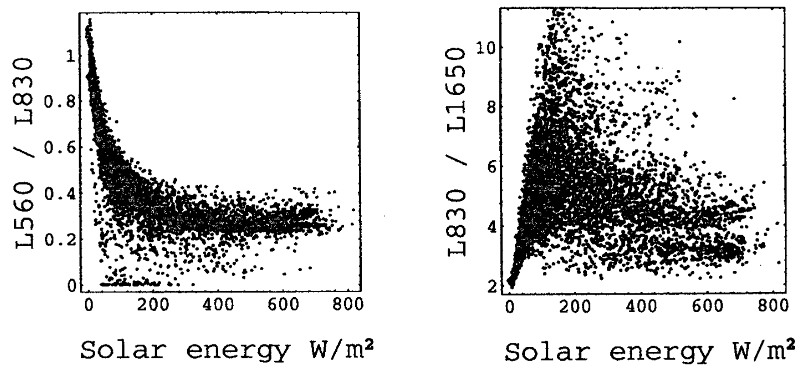


Fig. 4. Spectral radiance ratio indices versus solar energy. L560/L830 *(left) and* L830/L1650 *(right).*

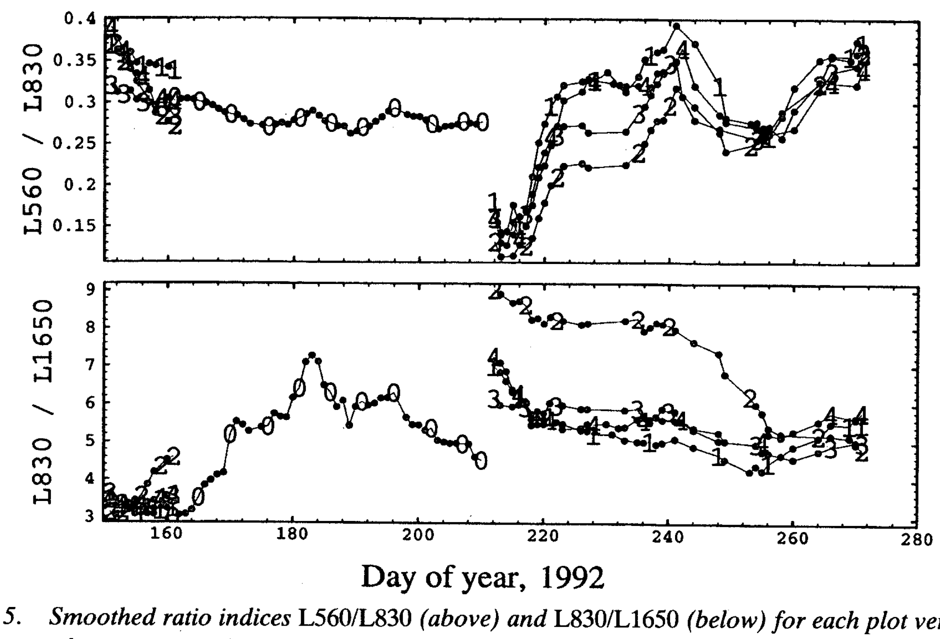


Fig. 5. Smoothed ratio indices L560/L830 *(above) and* L830/L1650 *(below) for each plot versus day of year. Numerals 0 to 4 indicate the plot number. The window width for the moving average calculation was 7 days in the smoothing procedure.*

red-edge characteristics. They observed short-term or oscillating variations in the reflectance, red-edge parameters and so on, and suggested that the oscillations were associated with rainfall and temperature events. From DOY260, curves of *L560/L830* for all the plots increased simultaneously; this might be caused by the autumn tints and falling leaves.

L830/L1650 of Plot #2 was relatively higher than the others during the summer growing season, and then declined from around DOY240 to be equalized with the other 3 plots' level at about DOY260. It was caused by the difference of plant cover. Plot #2 was covered about 70% by mountain birch trees (*B. tortuosa*), while the others were covered about 20 to 40% by black crowberry and 5 to 30% by dwarf birch (*B. nana*). The senescent stage of mountain birch leaves in autumn seemed to be detected by *L830/L1650.*

The results indicated the possibility to detect the stages of autumn tints and dead leaves of *B. tortuosa* and *B. nana* separately by combined use of the two spectral ratio indices such as *L560/L830* and *L830/L1650.*

3.2. *Bidirectional reflectances of subarctic plant canopies in early autumn*

3.2.1. Reflectance spectrum taken for vegetation around Kevo

Reflectances from three canopies of dwarf birch of different leaf colors are compared in Fig. 6. Reflectance factors at 660 nm increased along with the autumn leaf coloring, while reflectance at 560 nm changed very little. The latter band seemed to not be suitable for detecting the autumn change of dwarf birch.

Reflectances from a mountain birch tree with green leaves and reflectances from another tree with yellow leaves were plotted with pine tree and black crowberry spectra in Fig. 7. Autumn change of mountain birch may be sensed by reflectance at 660 nm. Reflectances from the black crowberry were rather low in all the bands measured. On the other hand, reflectances from pine trees were as high as those from mountain birch with green leaves.

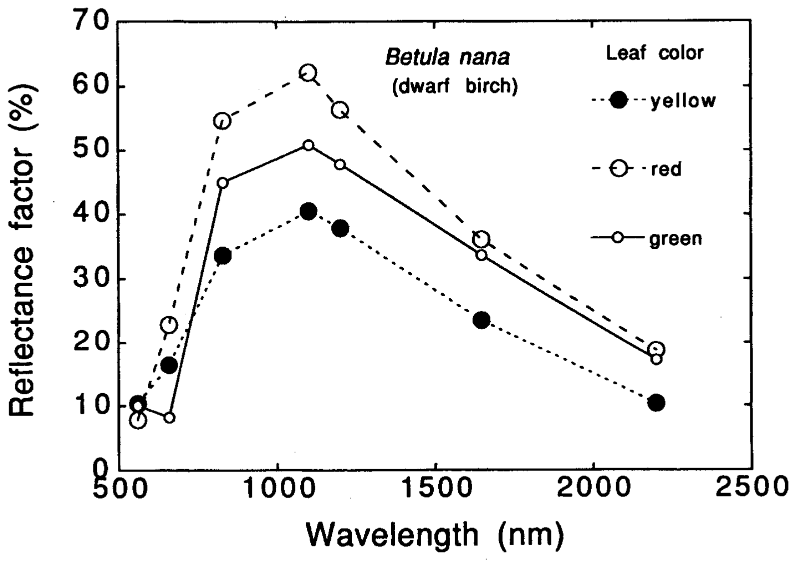


Fig. 6. Seven-band reflectance factors of dwarf birch canopies at Kevo.

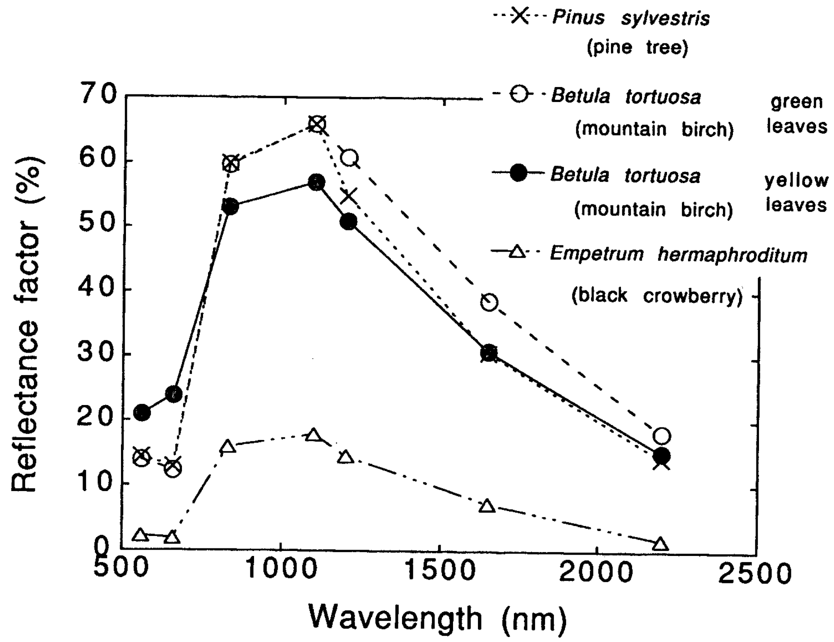


Fig. 7. Seven-band reflectance factors of mountain birch, pine and black crowberry canopies at Kevo.

3.2.2. Reflectance spectrum of peat bog plants at Apukka

Averages of reflectance factors collected from a peat bog at Apukka are plotted against wavelength in Fig. 8. The sky was fair and cloudless during the measurement. The soil moisture level of haircap moss (*Polytrichum* sp.) affected the reflectances in the near- and mid-infrared bands such as 1200, 1650 and 2200 nm. Near-infrared reflectances from mosses were lower than those from plants of greater biomass such as pine trees and sedges (*Carex* sp.).

4. Discussion

An elementary technique was tested in this report to analyze seasonal vegetation indices measured by the boom-mounted radiometer. The vegetation indices were calculated using the radiance data taken when the incident solar radiation was larger than 200 W/m^2. Even such a simple method seemed to be effective in a brief survey this year, but much work must be done to develop more advanced techniques. For example, solar elevation and position ought to be considered in future analyses.

The visible red band (660 nm) proved to be more useful than the green band (560 nm) for detection of autumn tints. In this season, the 660 nm band was not available from the boom-mounted 4-band radiometer because of the circuit malfunction. From the results mentioned above, the 660 nm band appears to be more useful than the 560 nm band for detecting the autumn changes of plants.

Wetness index is defined as a difference of weighted visible to near-infrared

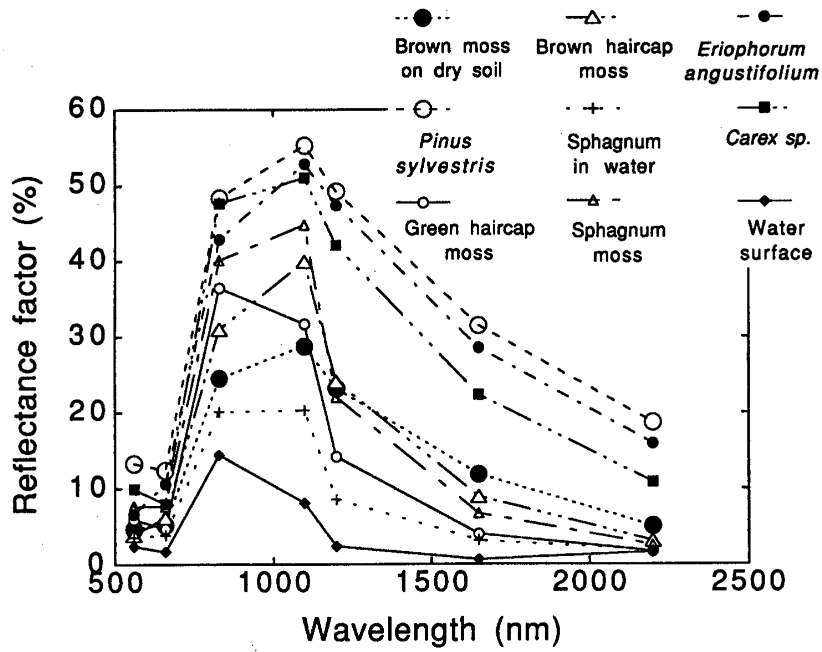


Fig. 8. Seven-band reflectance factors of peat bog plants measured at Apukka.

TM band reflectances and mid-infrared TM band reflectances. "Wetness" has been introduced to evaluate the forest age. The shadow effect and water content of the target are related to mid-infrared reflectance from the target (COHEN and SPIES, 1992). HUNT (1991) found that the mid- and near-infrared radiance ratio could be related to canopy equivalent water thickness (EWT). Seasonal and phenological change seemed to be also sensed by mid- and near infrared band reflectance ratios such as 830 nm/1650 nm in the data taken by our boom-mounted radiometer. These data will be utilized in the near future to find the proper technique for assessing boreal plant phenology.

We will replicate the experiment using the boom-mounted radiometer at Kevo in 1993. Canopy surface temperature will be also measured by an infrared thermometer attached to the rotating boom.

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